Testing and selection of filter media for dedusting
Part 2: Field measurements with a mobile filter probe derived from VDI/DIN 3926

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Meanwhile, almost all large manufacturers of cleanable filters conduct systematic filter tests in acc. with VDI/DIN guideline 3926 /1/. The results serve for comparative characterisation and evaluation of the filter media under exactly defined and controlled laboratory conditions, mainly in development and quality control. The corresponding tests are described in part 1 /2/. Due to the limited possibilities to reproduce the gas as well as the dust properties of 'real' dust-charged gasses that occur in practice in the laboratory, a mobile filter probe for conducting 'field tests' was developed and will be discussed in this article.

1. Introduction

Meanwhile, almost all large manufacturers of cleanable filter media conduct systematic filter tests in acc. with VDI/DIN guideline 3926 /1/. The results serve for comparative characterisation and evaluation of the filter media under exactly defined and controlled laboratory conditions, mainly in development and quality control.

Due to the limited possibilities to reproduce the gas as well as the dust properties of 'real' dust-charged gasses that occur in practice in the laboratory, the results can only be applied to a limited extent for the selection of a filter material for a certain application and/or the design resp. optimisation of a filter system. This also requires knowledge of the properties of a reference medium. Derived from the technology and approach applied in the laboratory, a mobile filter probe for the performance of „field tests" was developed in a further step.

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This method allows the direct comparison of different filter media available on the market based on the conditions prevailing in the gas flow to be cleaned. With some experience, it is also possible to use the obtained operating data for the design or optimisation of the filter system.

2. Basic ideas and objectives

The comparative evaluation of filter media based on measuring results includes the characteristic data described in part 1: Pressure drop progression, development of residual pressure drop and cycle time, weight increase of the filter sample and clean gas dust concentration. The behaviour charted in Fig. 13 and 14 (part 1) can be assumed as regular result, meaning an increase of the residual pressure drop, reduction of the cycle times, increased surface weight of the filter sample and, in most cases, improved dust separation, meaning a reduction of the dust content in the clean gas with increasing dusting of the filter sample. However, the latter cannot be safely assumed, as a bad dimensional stability or inhomogeneities in the design of the filter material for example, already leads to increased particle penetration after the ageing phase in the laboratory tests. Fig. 15 (part 1) illustrates the typical development of the filtration behaviour of a filter sample based on the initially concave progression of the pressure drop curve (with particle deposits in the depth of the medium) up to a pronounced convex curve progression after ageing, which inevitably leads to a reduction of the cycle times. This behaviour is more or less dominant with the different available filter media and illustrated in the diagram in Fig. 1. With „ideal" filtration behaviour (also see part 1, Fig. 8), a constant residual pressure drop on a low level and the build-up of a homogeneous filter cake at constant dust concentration and filter face velocity is assumed.

This leads to a linear pressure drop increase with the filtration time or the filter cake areal weight in the total course of a filtration cycle as described with equation 2 to 4 in part 1. In reality, the rise of the residual pressure drop as well as the increasing convex progression of the pressure drop curve after cleaning lead to

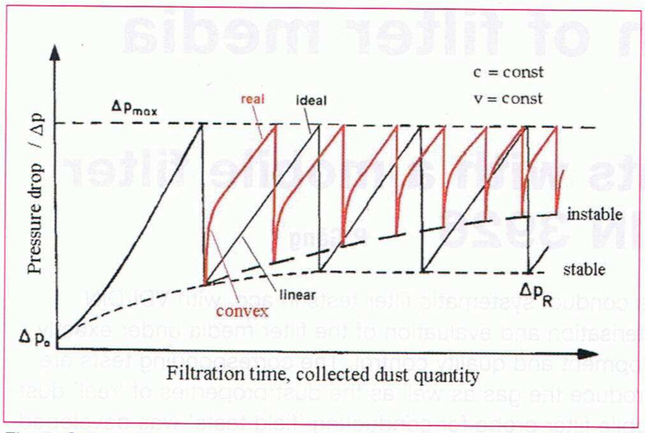

Fig. 1: Schematic pressure drop progression of a cleanable filter at „ideal" (black curve) and „real" (red curve) operating behaviour of a surface filter

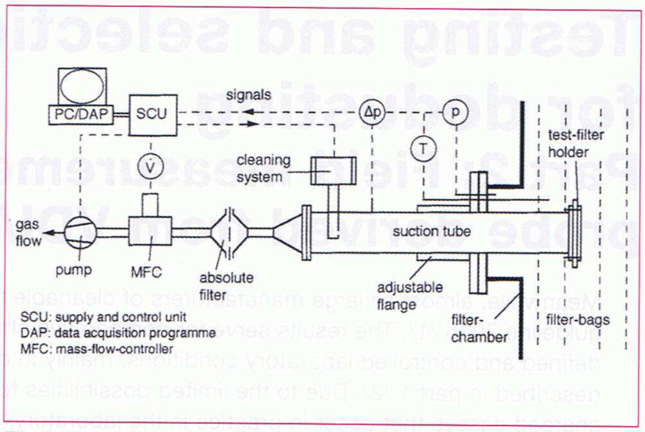

Fig. 2: Measuring set-up of the mobile filter probe on a pulse jet bag filter system

a continuous shortening of the linear curve share and thus a partially drastic shortening of the cycle times.

In practice, the extent to which these effects occur especially depend on all relevant parameters influencing the operating behaviour of a cleanable filter, especially the properties of the filter medium, the gas and dust properties (composition, temperature, chemical reactions, etc.), the system operation (filter face velocity, pressure drop flange to flange, etc.), the effectiveness of the cleaning system and the geometric properties of the filter system (e.g. flow distribution).

The design of a cleanable filter with a given operating volume flow initially requires the definition of the air-to-cloth ratio and thus of the required available filter surface. This results in the number of filter elements (usually filter bags) and finally the layout of the entire filter system. The second essential parameter is the projected resp. desired pressure drop of the system flange to flange, which must be kept constant in the long run during the entire system operation.

Here it becomes evident that knowledge of the long-term operating behaviour of the filter medium with the prevailing operating conditions would be a necessary requirement for the data-based design of the system. As this data is usually not available in sufficient quality when planning a system, one usually reverts to the experiences gained with similar application cases, which is tied to significant planning uncertainties and risks especially with difficult conditions.

At this point the concept of a mobile filter probe comes in. It allows the empirical determination of operating data, which can be regarded as a supplement to the available experiences and media data and significantly improve planning safety.

The measuring aims can basically be divided in three application-related categories:

- Screening and selection of filter media through fast comparison of flat, round filter samples
- Optimisation of operating conditions by varying the operating parameters (e.g. filter face velocity, tank pressure, valve opening times) with precisely known and reproducible conditions
- Monitoring of the filter operation and dust sampling, whereby due to parallel operation with the filter system, „improper operating conditions" are rapidly identified and can be documented by taking filter samples incl. filter cakes, especially during the commissioning and/or warranty phases when setting up systems or equipping existing systems with new filter bags.

One important issue for the plant operator is that the measurements can usually be performed without interrupting the system operation. The extracted volume flow is so small that it can be neglected compared to the gas flow cleaned in the filter plant. The exchange of filter samples, especially with system in suction operation, is also effortless in most cases and does not require any special preparations.

The aim of measuring is to determine a possible „operating window" for a certain filter medium besides the selection of a suitable medium based on the prevailing operating conditions. Here it is assumed that the conditions in a filter system are selected in such a way that an operating point will be located on the linear section of the pressure drop curve. Operation of the system in the convex section of the pressure drop curve should be avoided as this leads to very frequent cleaning and – quite likely – to permanent cleaning. Stable operation can be achieved under the other prevailing conditions either by adapting the air-to-cloth ratio, meaning changing the filtration surface and/or the volume flow. As this is often impossible in practice, the only other options are: increasing the maximum pressure drop flange to flange or optimising the cleaning system as free parameters to shift the operating point into the linear section of the pressure drop curve.

3. Layout of the mobile filter probe

The core piece of the system basically corresponds to the horizontal part of the laboratory system described in part 1, chapter 2 /2/ and consists of an extraction pipe with filter holder for round, flat filter samples with a free diameter of 140 mm, a cleaning system with pressure tank, membrane valve and blow pipe and an absolute filter for gravimetric determination of the clean gas concentration (see Fig. 2 and 3).

The suction pipe with the filter sample is positioned between the filter bags with a flange attached to the side wall of the filter system with DN250 mm and connected gas-tight with a moveable retainer flange (Fig. 4).

All parts carrying gas can be heated if required up to and including the absolute filter. The basic structure of the system additionally consists of a control for compressed air pulse cleaning, a pump, a mass-flow controller (MFC) for the extracted gas volume flow, a differential pressure sensor for measuring the pressure drop of the filter sample, as well as pressure and temperature sensors for measuring the gas state parameters. All components are supplied by a central operating unit, the measuring data volume flow, temperature, pressure, differential pressure and tank pressure are recorded analog and then digitised. Control of the entire system as well as data recording takes place largely automated with a PC and can be remote-controlled via a telephone modem or broadband connection.

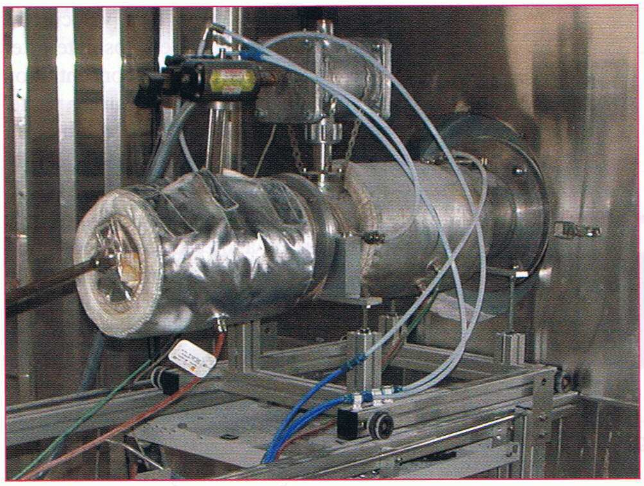

Fig. 3: Mobile filter probe installed in a pulse jet bag filter chamber

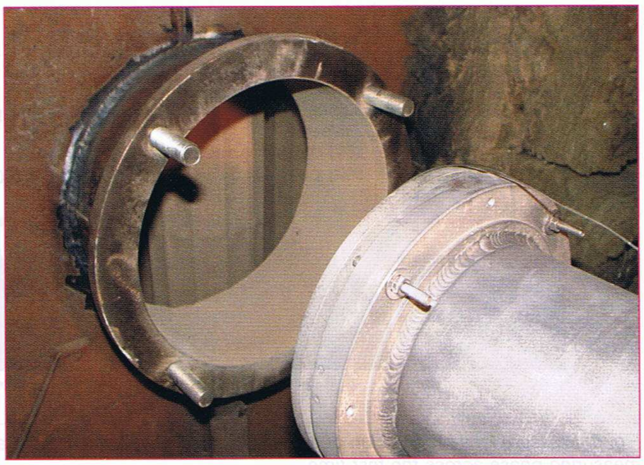

Fig. 4: Connection flange DN250 for the mobile filter probe on the side wall of a filter

When selecting the measuring location, it must be made sure that the operating conditions prevailing there are as representative as possible for plant operation. Usually, a filter bag is removed and the probe positioned at half the height of the bag from the side. Now the filtration tests can be performed at „real" conditions in the filter chamber, which does, however, require exact knowledge of the operating conditions on the filter sample.

Generally, the entire suction pipe including the absolute filter must be heated from the outside with heating cuffs (see Fig. 3) to prevent condensation of vapours. Downstream from the absolute filter, the vapour is condensed in a cooler to protect the measuring devices and the pump, the condensate is trapped, and then the exhaust gas is reheated again to 30-50°C prior to volume flow measuring or control and the pump. Behind the condensation track, it is possible to attach an additional adsorption unit for separating gaseous components, if required. The condensate is trapped in a vacuum-tight container and its weight increase determined continually with a scale.

The measurements performed with the mobile filter probe so far were mainly conducted on bag filter systems with pulse jet cleaning as described above. Measuring in bag housings with bags streamed

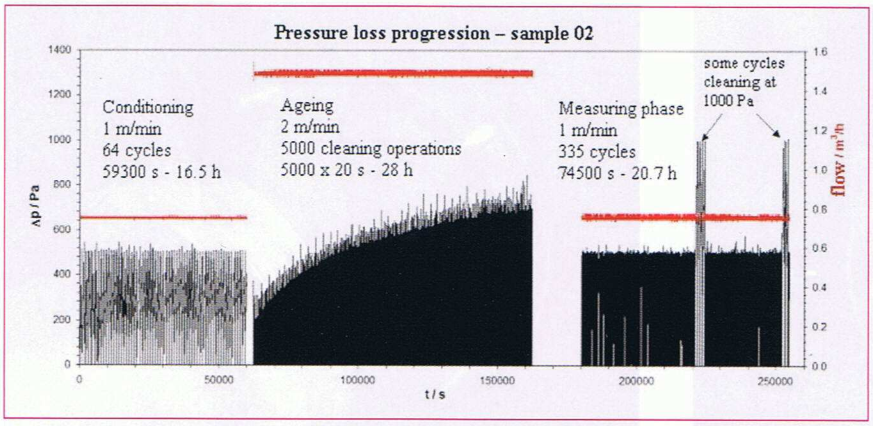

Fig. 5: Pressure loss progression of a filter sample during conditioning, ageing and subsequent measuring phase across the test time

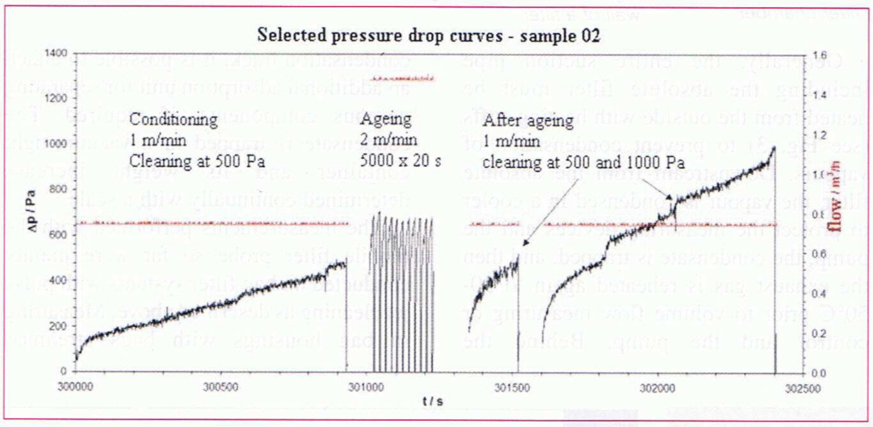

Fig. 6: Typical selected pressure drop curves recorded during the test phases conditioning, ageing and post-ageing

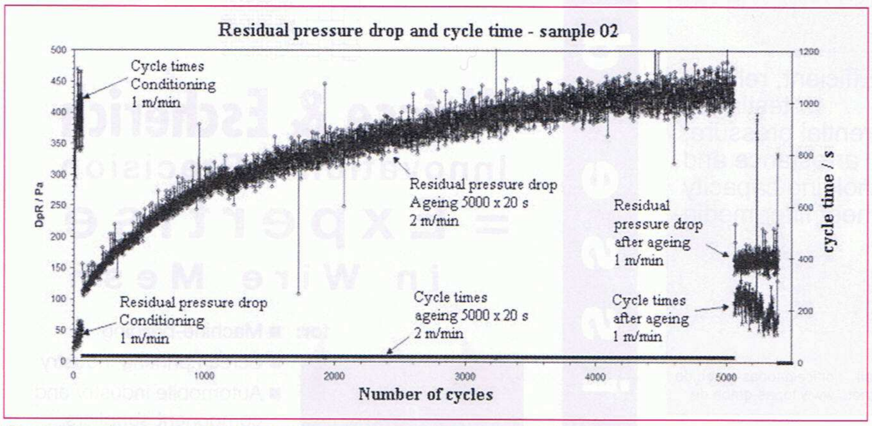

Fig. 7: Development of the residual pressure drop and cycle times of a filter sample with conditioning, ageing and measuring phase after ageing across the number of cycles

against from the inside or on pipelines are principally possible and were already realised, but do require additional measures and will not be discussed in the scope of this article.

4. Measuring procedure

Analog to the procedure in acc. with VDI/DIN 3926, the filter medium is conditioned at the start of measuring, meaning it is dusted in the respective filter systems at an air-to-cloth ratio of 1-1.5 times the value and cleaned at the differential pressure prevailing in the system. Conditioning, which takes approx. 1 day, is followed by the so-called „ageing“ phase, which comprises 5,000 cleaning operations with an interval time of 20 s and is performed at twice the value of the face velocity during the conditioning phase. The doubling of the face velocity accommodates the fact that when cleaning a bag series in a filter system, the face velocity for this bag series is significantly higher until pressure drop compensation is reached. The ageing phase is followed by another measuring phase with differential pressure-controlled cleaning and the same face velocity as during conditioning. A new absolute filter is used to measure the dust concentration in the clean gas for each measuring phase, whereby conditioning and ageing are combined in some cases to save travel expenses to the system.

Fig. 5 shows an example of the progression of a measurement operation with a total duration of approx. 3 days. In this case, the face velocity was 1 m/min with cleaning at 500 Pa and during ageing 2 m/min. This overview diagram already shows a significant reduction of the cycle times after ageing compared to conditioning.

This change of the cycle duration and curve characteristic becomes clearer in Fig. 6 in which the individual cycles are illustrated enlarged. It is possible to detect a very long cycle time in the conditioning phase due to the low residual pressure drop with rising linear pressure drop, the short time-controlled cycles however with high pressure drop during ageing (especially due to the doubling of the speed) and the short cycle duration after ageing with a pronounced convex curve shape when cleaning at 500 Pa. One can also detect that a linear rise of the pressure drop with filter cake build-up can be achieved again when increasing the pressure drop for cleaning to values of >500 Pa again (here to 1000 Pa).

Another type of illustration of the test results with additional information is shown in Fig. 7, in which the development of the residual pressure drops and cycle times are displayed across the number of cycles. It clearly shows the increase of the residual pressure drop with ageing as well as the shortening of the cycle times. In the illustrated example, it becomes evident that the residual pressure drop towards the end of the ageing phase continues increasing, and that the cycle times after ageing continue to decrease.

The results shown in Fig. 5 to 7 serve as data basis for evaluation of different filter samples together with the measured clean gas values and the increase of the surface mass of the filter sample.

5. Exemplary results of field tests

When performing measuring operations on different systems, there may be extreme differences in the prevailing filtration conditions with respect to the gas and dust composition, the operating temperatures or the desired air-to-cloth ratio in the system and pressure drop levels.

This already becomes evident in the visual inspection of the filter samples in Fig. 8 and 9, which were dusted under different conditions across several

Fig. 8: Filter sample dusted with excellently agglomerating dust from a municipal waste incinerator after cleaning with heavy encrustation

Fig. 9: Filter sample dusted with badly agglomerating dust after cleaning - no pronounced filter cake build-up

thousand filtration and cleaning cycles. Both samples are shown in cleaned state, whereby a clear crust formation is visible on the sample in Fig. 8, which can be explained with the special dust composition and passing through the dew point. It comes as no surprise that steep pressure drop rises after cleaning with high residual pressure drop and short cycle times were observed with this sample.

Compared to this, the sample in Fig. 9 was dusted in a facility for aluminium oxide production. This dust shows a very bad agglomeration behaviour with slight filter cake formation, which leads to a strong penetration into the filter medium and also an increased particle penetration to the clean gas.

Fig. 10 and 11 show the pressure drop curves of two different filter media with the same scaling, which were measured under the same conditions after the ageing phase on a production facility in the chemical industry. As there were no essential differences in both samples with respect to the achieved dust content in the clean gas, the filtration behaviour was used as decision criterion. Of decisive importance here was the system-based limitation of the filter system's pressure drop to 14 mbar. One can immediately detect the shorter cycle duration for the sample in Fig. 10 compared to that in Fig. 11, which is caused by the pronouncedly convex curve progression after cleaning, because the increases in the linear section of both pressure drop curves are almost equal. (This corresponds to the theory regarding homogeneous filter cake formation at otherwise equal conditions, see Fig. 1). The linear curve progression in Fig. 10 starts at approx. 900 Pa, in Fig. 11, however, already at approx. 300 Pa. For comparison with the filter system, the system pressure drop without medium must be added to the pressure drop of the filter sample measured with the mobile probe, which was estimated to be approx. 3 mbar. For the sample in Fig. 10, this results in a required system pressure drop flange to flange of at least 12 mbar to place the operating point at the start of the linear curve section, and of at least 15 mbar if one wants to move the operating

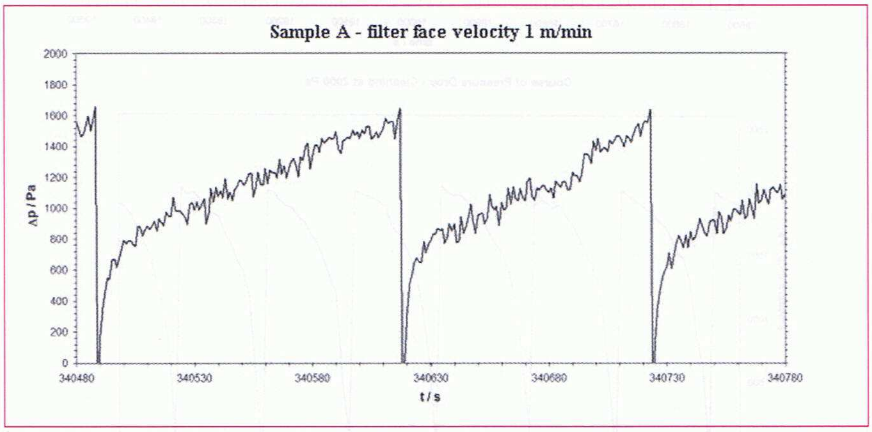

Fig. 10: Pressure drop of a filter sample after ageing - pronounced convex curve progression shortly after cleaning - linear curve progression starting approx. 900 Pa

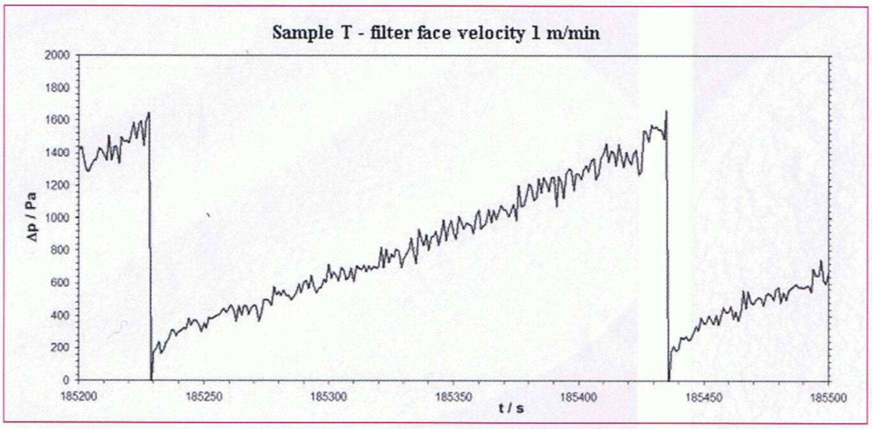

Fig. 11: Pressure drop of a filter sample after ageing - early start of linear progression at approx. 300 Pa

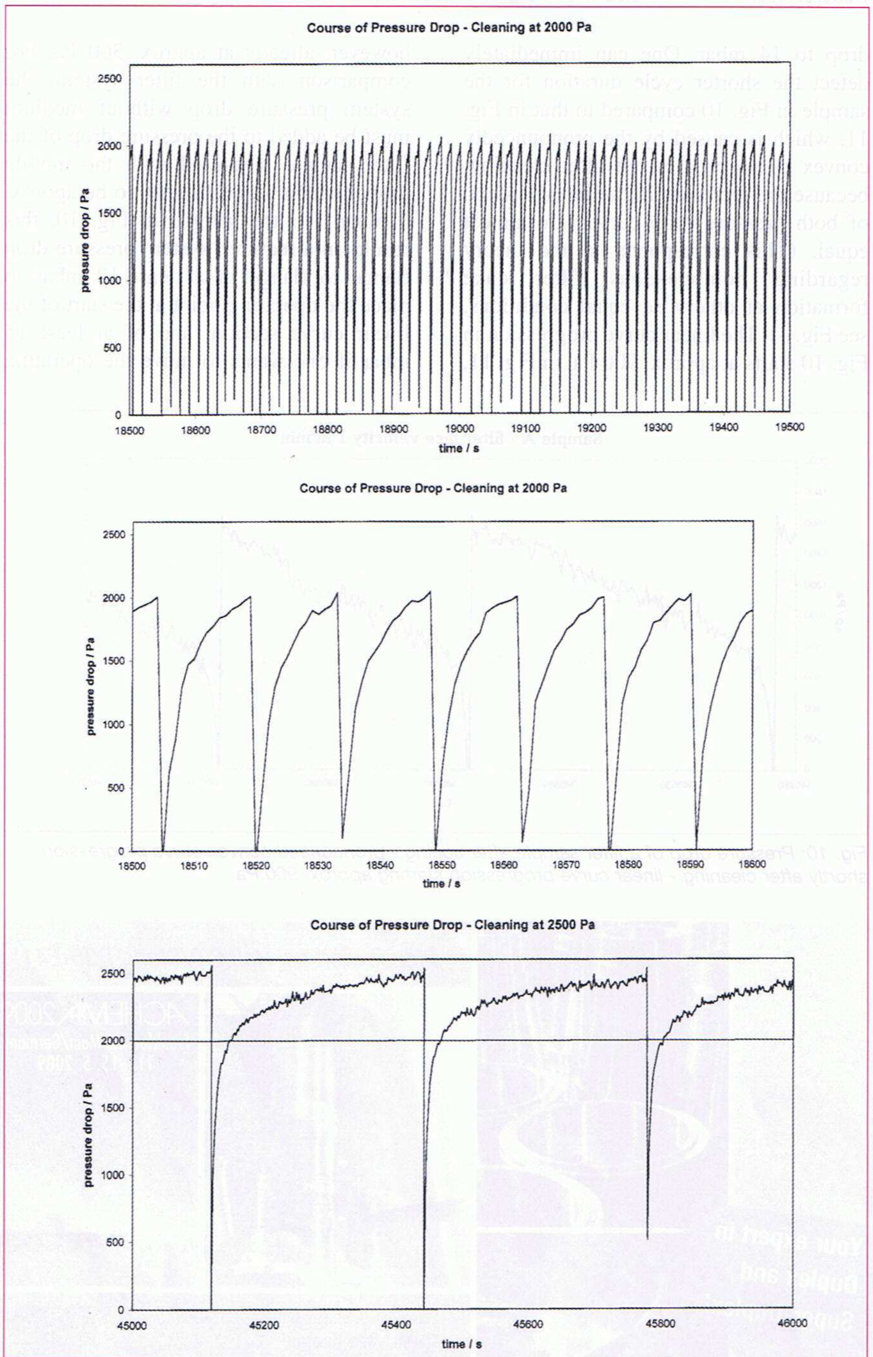

Fig. 12: Pressure drop curves at different cleaning pressure drop but otherwise equal conditions - top and bottom diagram same time axis (1000 s) - centre time axis 100 s

point at least 3 bar into the linear section of the curve. At a system pressure drop of 14 bar, this therefore poses the risk that an operating point results in proximity to or in the range of the convex section of the pressure drop curve and thus a significantly increased cleaning frequency up to permanent cleaning. Comparison with the pressure drop curve in Fig. 11 shows that with this medium, there is apparently a significantly larger margin for the available pressure drop range.

The results in Fig. 12 are another example for the significance of selecting the right „operating window“ with respect to the system's pressure drop flange to flange with a given air-to-cloth ratio and filter surface. Very short filtration cycles were initially observed when measuring with the mobile filter probe with the selected setting and cleaning of the sample at 2.000 Pa (Fig. 12, top), which correspond to permanent cleaning. In the enlargement in Fig. 12 (center), one can clearly see that the pressure drop after cleaning rises steeply and with a convex curve progression, and that cake filtration apparently does not yet take.

Increasing the pressure drop for triggering the cleaning operation from 2,000 to 2,500 Pa results in the completely different behaviour shown in the bottom part of Fig. 12 at otherwise identical filtration and cleaning conditions. The duration of the filtration cycles increases from approx. 15 s to approx. 330 s, which can apparently be attributed to the fact that a filter cake is build up above a pressure drop of approx. 2,200 Pa, and that the pressure drop increase thus becomes increasingly linear after the convex starting phase.

When evaluating the measuring results obtained with the filter probe, one has to consider that filter plants are not test systems with constant conditions, but most often large facilities whose dirty gas properties do not have to be chronologically constant. Changes to the properties of the dirty gas due to influences from the previous process may however have significant influences on the filtration behaviour.

This also becomes apparent with the results in Fig. 13, which show a pronounced periodical time change of the residual pressure drops and cycle times of an already conditioned filter sample. Especially the cycle times only amount to approx. 1/3 of the initial values at the end of a period. And finally, it was possible to show that this initially inexplicable behaviour is related to the soot blow of the heat exchangers and clearly correlates with the steam addition by the cleaning nozzles. This process is performed approximately once per work shift, whereby a slight, less pronounced reduction of the pressure drop and/or a prolongation of the cleaning cycle times is observed regularly in the system as well, despite the correlating increase of the steam content and the dust concentration. This can be explained by the fact that although the dust concentration increases during soot blowing, a net reduction of the pressure drop of the dust cake results due to a shift of the particle size distribution towards coarser particles.

Based on the presented results, the system was equipped with a recirculation unit for already separated dust, which resulted in a significant improvement of the filtration (pressure drop flange to flange, cleaning cycle times). This made it possible to prevent the reduction of the filter load through enlargement of the filter surface.

6. Conclusion

When determining a possible „operating window" for a certain filter medium, it was assumed that the conditions in a filter system should be selected in such a way that an operating point in the linear section of the pressure drop curve results. Operation of the system in the convex section of the pressure drop curve should be avoided as this leads to very frequent cleaning and - under certain circumstances - permanent cleaning.

In field tests for selecting suitable filter media at given operating conditions as well as optimising system operation and for the specification of a so-called „operating window", the mobile filter probe turned out to be a very useful tool.

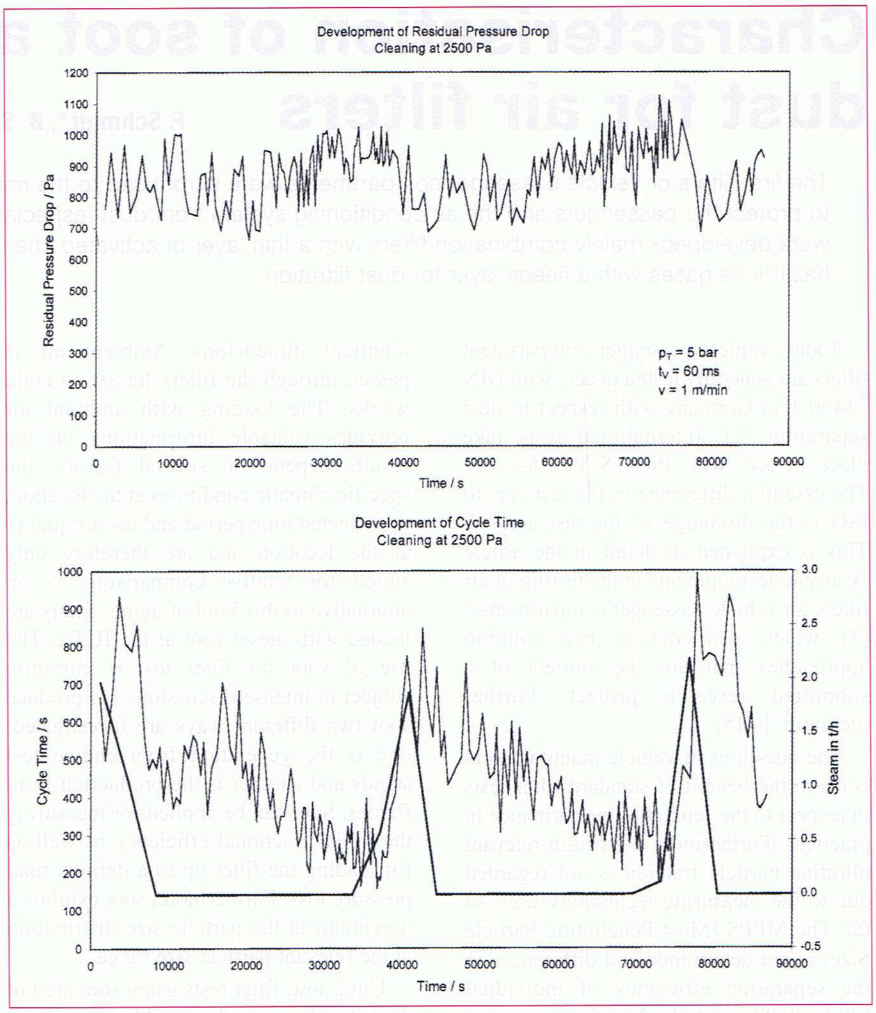

Fig. 13: Influence of the cleaning of heat exchangers in a municipal incinerator via soot blowing by means of steam jets on the residual pressure drop (top) and cycle times (bottom) across the test time at constant filtration and cleaning conditions

Literature

/1/ VDI guideline 3926: „Testing of cleanable filter media", Part 1, "Standard test for evaluation of cleanable filter media", VDI/DIN Handbuch Reinhaltung der Luft, Band 6, October 2004

/2/ Testing and selection of filter media for dedusting part 1: Standard laboratory tests in acc. with VDI/DIN 3926, F & S Filtrieren und Separieren, volume 22 (2008) no. 2, p. 58-67